

An Unsolicited Proposal

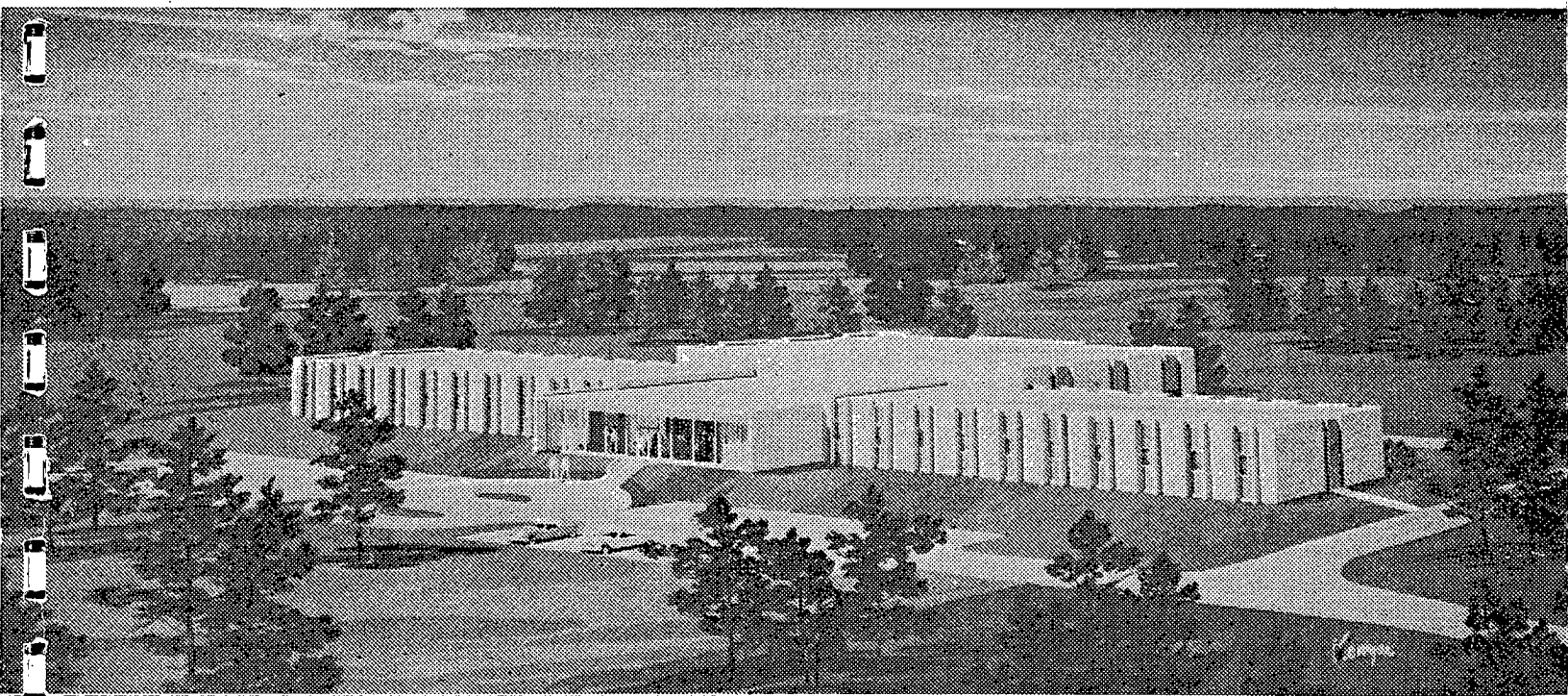
For

"REDUCING TO PRACTICE CERTAIN DISCOVERIES RELATING TO THE OPTICAL PHENOMENA OF REAR PROJECTION SCREENS"

Submitted to:

THE UNITED STATES GOVERNMENT

Electronics Research



CORNING ELECTRONICS

A DIVISION OF CORNING GLASS WORKS

RALEIGH, NORTH CAROLINA

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The accompanying proposal relates to the evaluation and application of materials; some of which are the result of Corning's inventions in the composition, processing, and manufacturing of glass. Improvements which may be made thereon in the course of work being performed under the proposed program would be regarded as "Subject Inventions" under which the Government would obtain free and non-exclusive rights for Government end-use in accordance with the provisions of ASPR9-107.5(b) 1. It is not our intent to grant to the Government rights under any background inventions or technology, including glass composition and processing.

AN UNSOLICITED PROPOSAL

For

"REDUCING TO PRACTICE CERTAIN DISCOVERIES

RELATING TO THE OPTICAL PHENOMENA OF

REAR PROJECTION SCREENS"

Submitted to

THE UNITED STATES GOVERNMENT

By

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January 31, 1968

I N D E X

	Page
I. <u>INTRODUCTION</u>	I - 1
A. OBJECTIVE	I - 1
B. COMPANY BACKGROUND	I - 1
C. ATTACK TO BE FOLLOWED	I - 3
II. <u>RESULTS EXPECTED</u>	II - 1
III. <u>TECHNICAL DISCUSSION</u>	III - 1
A. ANALYSIS OF SCREEN PERFORMANCE REQUIREMENTS	III - 1
B. INVESTIGATION OF DARKENED SUBSTRATES	III - 3
C. REDUCTION OF SURFACE REFLECTIONS	III - 5
D. LENTICULAR SCREENS	III - 8
E. DISCRETE-PARTICLE SCREEN PERFORMANCE IMPROVEMENT.	III - 11
IV. <u>RECOMMENDED PROGRAM</u>	IV - 1
V. <u>PERSONNEL</u>	V - 1
VI. <u>FACILITIES</u>	VI - 1

I. INTRODUCTION

A. OBJECTIVE

Corning Glass Works wishes to propose that the discoveries made concerning the mechanism and phenomena involved in rear projection screen design and performance under a contract now just concluding be carried forward and put to practical application. This will include the further exploitation of the theories developed and will entail the selection and combination of the materials found to be most suitable to fabricate screens having enhanced performance in the areas of the most critical response requirements.

B. COMPANY BACKGROUND

Under the afore mentioned contract, Corning has been engaged since mid-1965 in the application of glass, glass-ceramic and ceramic particles as light scatters to construct improved rear projection screens. Particular attention has been given to brightness and brightness variation, efficiency, resolution, contrast, and diffuse reflection. A major part of the work has been devoted to determining the effects on these parameters of the particles themselves and their properties, the properties of the materials serving as vehicles for the particles and the properties of the substrates for the screens.

I - 2

In addition to deriving the significant performance parameters, the equipment (at Corning's expense) was designed and built for determining them. As an example, a MTF analyzer is now available which by design and operational procedure is particularly suited for rear projection screen evaluation. The Laboratory is unusually well equipped at this time for going forward in this field as will be noted from the "Instrumentation" section in the final report.

In the course of the work several distinct approaches were taken to the creation of optimum screens. The first of these was the use of the glass-ceramic process for developing the type of crystalline volume scatters as dictated by theory. The practical results agreed very well with predicted results, but the demands of resolution necessitated such a thin cross section as to be impractical. Several methods were then successfully developed for incorporating the scattering particles in thin layers. While good results were obtained, it became evident that one important parameter, contrast, could be greatly improved through manipulation of the transmission of the substrate. This will be discussed in more detail in the

I - 3

proposed program.

A different approach to the problem was the use of shaped light refractors. One attempt incorporating FOTOFORM glass was successful in developing the lenticular surface but unwanted crystal growth degraded the resolution. Theoretical examination of screens formed from refracting beads and properly masked showed great promise. Reduction to practice in the time still available was not possible but the approach deserves further effort.

Throughout the course of the project, considerable experience was had in the subjective evaluation of screens. It is felt that this in conjunction with the new instrumentation will be of value in reassessing the comparative importance of screen performance criteria. Such information would be of great value in optimizing the results.

C. ATTACK TO BE FOLLOWED

The experience and background information gained from the recently completed contract will be drawn on very

I - 4

heavily. It is expected that the contracting agency will be able to supply further background in the physiology of seeing and the human factors involved in viewing. The program will then begin by combining and drawing on these information sources to establish a basis for reappraising the criteria for screen performance. A systems point of view will be taken which will encompass the screen, the viewing machine and the viewer.

From the original work, it is quite evident already that contrast is one of the most important criteria. The systems-type analysis will clarify and quantify this parameter which will be the first objective of the experimental portion of the project. Since the theoretical and practical indications point towards the need for controlled absorption in the substrate, effort will be directed towards this. Towards the same objective of contrast enhancement, work will also be originated on^{started} optical coatings to minimize the sensitivity to ambient light.

Refraction rather than scattering offers an alternate approach having theoretical advantages in light control

I - 5

and efficiency. A potential disadvantage is limited resolution since it depends on the attainment of very small lenticules. It is thought to be worthwhile investigating further such screens due to the fact that potential improvement is appreciably greater than the improvement theoretically available in discrete-particle screens.

II. RESULTS EXPECTED

The analysis of screen performance requirements is expected to lead to the optimum choice of parameters of Corning screens and a careful comparison of Corning and other commercial screens. The analysis will also guide the screen development program during the program.

Experimental study is expected to confirm theoretical predictions relating to the advantages of using an absorbing substrate to reduce stray light and maintain screen contrast.

In the course of this work several approaches to obtaining neutral density substrates will be investigated and it is expected that one of these substrates will be integrated into practical rear projection screens.

There is no real doubt that a useful reduction of surface reflections for glass substrate screens can be achieved.

Anti-reflection coating of flexible substrate screens appears to offer difficulties. Large flexible substrate screens are easier to make than rigid substrate screens. A compromise may be to coat a glass substrate and form a flexible substrate screen separately and then assemble the flexible substrate onto the glass substrate.

II - 2

Results from the lenticular screen work will be strongly dependent on the successful formulation of a configuration which is both optically efficient and capable of fabrication.

The theoretical work required to relate screen physical properties to optical properties will disclose any theoretical performance limitations which have not yet been recognized, and will allow maximum flexibility in choice of optical properties.

Development of workable masking techniques is expected to result in lenticular screens having low ambient light sensitivity. The fabrication investigation is expected to determine the feasibility of fabricating lenticular screens which have the conceptual advantages discussed in Section III.

Sample screens of candidate configurations will be made.

Theoretical and experimental investigations are expected to result in a clearer understanding of the discrete-particle screen. Discrete-particle screens with better efficiency and diffuse reflectance are expected from the work discussed in Section III-E.

II - 3

Constant attention will be given to the cost and producibility of the screens potentially resulting from the investigative part of the project. The final product will be practical on both counts.

Summary reports will be provided each accounting period (4 weeks). A final report will also be provided.

Sufficient screen material of the best selection will be provided for testing on a 30" x 30" viewer. It will be in a single continuous piece if practical. Available equipment may limit the size of a single sheet to something smaller, but sufficient sheets will be made to cover the 30" x 30" aperture.

III. TECHNICAL DISCUSSION

A. ANALYSIS OF SCREEN PERFORMANCE REQUIREMENTS

The use of darkening material in a rear projection screen can improve the contrast of the display at the expense of brightness. The most favorable screen parameters depend on many of the projection system and observer parameters. The overall objective is to make the input contrast of 1000 to 1 perceivable to the observer in the presence of ambient light.

2:1

It is planned to relate Corning screen parameters to physiological and viewer data supplied by the Government Agency. This comparison will enable an optimum choice of existing Corning screen parameters to be made and compared to the system performance with the Polacoat 60 screen. From this system comparison the advantages to be gained by enhancement of Corning screen characteristics can be determined.

There is no doubt that darkening of the screen substrate and reduction of ambient light reflection will be desirable. However, the precise degree of darkening requires quantitative determination.

If the darkening is somewhat wavelength sensitive, zero dissipation reflective color correction filters can be

III - 2

inserted into the projector. The use of water cells and dielectric thin film filters can filter the non-visible components from the source lamp in the projector, perhaps enabling more light to be provided in the projector beam. A scheme to immerse the transparency in a liquid would considerably increase the power rating of the transparency.

Careful design of the observer's room will help reduce the ambient light incident on the screen. Black walls, at least in the areas contributing to specular reflection, will greatly reduce the specular reflection.

LIGHTING
PANELS

A relatively long focal length projection lens will make the system more tolerant of screen sag defocusing effects than a short focal length lens system. If the screen plane is horizontal, with the observers looking down at it, the sag is in the reverse direction from the normal focal plane curvature so that a rigid substrate may be preferable to a flexible substrate.

If a systems approach is taken, some of the findings relating to optimizing screen performance may suggest modifications in the viewer along the afore mentioned lines.

III - 3

B. INVESTIGATION OF DARKENED SUBSTRATES

Theoretical investigations indicate that a loss of image contrast, an increase in sensitivity to ambient light, and a lower than necessary efficiency can occur when rear projection screens consist of a diffusing layer, containing an absorbing material, and a transparent, non-absorbing substrate. All known rear projection screens, that exhibit high resolution, are fabricated by forming a diffusing layer on a clear substrate. These screens are made less sensitive to ambient light by adding some absorbing material to the diffusing layer. This solution is undesirable not only because the efficiency of the projection is reduced, but also because a significant fraction of the ambient light is backscattered close to the screen surface nearer the viewer, and passes through very little of the absorbing material.

A more effective way of reducing the diffuse reflectance would be to place an absorbing layer next to, and on the viewing side of the diffusing layer. This ensures that all the diffusely reflected ambient light passes completely through the absorbing layer twice. The absorbing material should now be more effective in reducing the

III - 4

diffuse reflectance for a given loss of projection irradiance; therefore, less absorption is needed and the efficiency of the screen can be improved. This absorbing layer should also greatly reduce the fraction of ambient light trapped in the substrate by total reflection, after being diffusely reflected, hence reducing the apparent diffuse reflectance still further.

In addition, part of the projector light is trapped by the substrate, propagates across the screen, and contributes unwanted light to adjacent areas, which reduces image contrast. When an absorbing substrate is used, the long light path causes a substantial reduction in the trapped light thereby maintaining image contrast.

Experimental investigations are needed to identify suitable absorbing substrates and to determine the degree to which these advantages can be practically attained. If "neutral" density is difficult to achieve, some color correction in the projector source should be considered.

It is also necessary to investigate the trade-offs between efficiency, ambient light rejection, and contrast in order to be able to specify the optimum amount of absorption needed for a variety of different viewing requirements.

III - 5

C. REDUCTION OF SURFACE REFLECTIONS

In the absence of some means to reduce surface reflections they will determine a lower limit to the diffuse or specular reflectance obtainable with a rear projection screen. A rough surface towards the viewer will give diffuse reflectance and a smooth surface will give specular reflectance. Surface reflections will also cause loss of screen efficiency although this loss will be much less significant for the system than the ambient light reflection.

Fresnel reflections occur whenever a discontinuity of refractive index occurs such as at a surface. The proportion of vertically polarized light reflected at a plane surface is given by:

$$R \text{ (Perpendicular)} = \frac{\tan^2 (\theta_i - \theta_t)}{\tan^2 (\theta_i + \theta_t)}$$

where θ_i is the incident angle and θ_t the angle of the transmitted ray. At normal incidence the proportion of light reflected reduces to:

$$R = \frac{(N-1)^2}{(N+1)^2}$$

where N is the ratio of the two refractive indices at the discontinuity. The corresponding relations for

III - 6

horizontally polarized light are:

$$R \text{ (Parallel)} = \frac{\sin^2 (\theta_i - \theta_t)}{\sin^2 (\theta_i + \theta_t)}$$

and

$$R = \frac{(N-1)^2}{(N+1)^2}$$

Typically, an air to transparent material interface gives about 5% reflection up to about 45° for equal amounts of vertical and horizontal polarization (often referred to as unpolarized light). As the larger angle (θ_i or θ_t) approaches 90° , reflection approaches 100%. For vertical polarization where $\theta_i + \theta_t = 90^\circ$, no reflection occurs and the angle is known as the Brewster angle.

Two types of approaches to reduce surface reflections exist. One approach is to set up extra Fresnel reflections which cancel the surface reflections. One or more layers of thin material of carefully chosen refractive index and thickness are commonly used. Reflection reduction to below 1% over the visual waveband from 0 to 45° angle of incidence can be obtained. Various schemes and performance characteristics are discussed in MIL-HDBK-141, (Military Standardization Handbook, Optical

III - 7

Design) section 20.3.

The techniques available for depositing the thin layers largely determine the success of the reflection cancellation approach. For glass and other tough substrates evaporation in a vacuum is the dominant approach.

Accurate film thickness monitors are available enabling calculated performance (for the materials used) to be achieved. The choice of low refractive index materials used in the films tends to limit the achievable performance. To our knowledge, pieces 40" square have been single layer vacuum coated and 40" x 20" pieces have been tri-layer coated. During coating deposition it is preferable to heat the substrate to give good adhesion, thus the order of application of the rear projection screen making processes must be carefully considered. The use of vacuum deposited coatings with a flexible plastic substrate may not be practical due to the heating required.

Other approaches to the formation of thin films are possible such as chemical reaction in a vapor or liquid or anodization. Some of these methods may be feasible for use with large plastic substrates depending, among

III - 8

other factors, on the precision of control available.

The second approach to reduce surface reflections is to provide a gradual change of refractive index between air and the substrate. This change should extend over at least half a wavelength thickness. This scheme is wideband and insensitive to angle of incidence and can be implemented at microwave frequencies but satisfactory optical material is not available.

D. LENTICULAR SCREENS

Lenticular, or lens-like, screens operate by refraction of light rather than by light scattering. One such screen consists of a plane matrix of very small lenses. Each small lens acts as an image transfer element, taking a small element of an image which is projected on the screen and transmitting and spreading the light from the image element over the viewing field. The size of the individual lenticules must be kept small if good resolution properties are to be obtained.

An ideal rear projection screen, for most applications, would have 100% transmission efficiency, constant brightness within a specified range of viewing angles,

III - 9

and zero diffuse reflectance. The impossibility of obtaining a scattering screen which simultaneously satisfies these requirements has been established. Lenticular screens, however, are not subject to the same trade-offs and limitations as scattering screens, and properly designed lenticular screens can conceivably approach these ideal requirements. Provided that care is taken to avoid total internal reflection of projector light and that the lenticules are close-packed with no void areas in between, the efficiency of lenticular screens is limited only by surface reflection losses. Ambient light sensitivity can be kept small by designing the screen to transmit or absorb ambient light. The large range of angles at which ambient light strikes all points of the screen leads to the use of an absorbing mask on the viewing side. All the projector light is focused through small openings in the mask.

By the use of an aspheric shape for the individual lenticules, screens exhibiting constant brightness over a specified range of viewing angles are possible, without a sacrifice in efficiency. Spherical lenticules will

III - 10

give an approximation to constant brightness at smaller viewing angles. The only mechanism for color distortion in lenticular screens is dispersion, which is a small effect compared to the wavelength dependence inherent in scattering screens.

The major problem in the development of practical lenticular screens is fabrication. The periphery of the individual lenticles must have a shape which allows close-packing with no void areas; e.g. triangular, rectangular, hexagonal, etc. The brightness uniformity of lenticular screens is dependent on lenticle curvature, so it is desirable that this curvature should be controllable. Workable masking techniques are needed in order to obtain superior ambient light sensitivity characteristics. All of these problems are made more complex by the requirement of small close-packed lenticles, preferably less than 20 microns in diameter, to meet resolution requirements.

Based on the preceding discussion, the following program for development of lenticular screens is proposed:

III - 11

1. Seek configurations which will allow the realization of the conceptual advantages. These configurations will be analyzed to determine the screen properties expected.
2. Investigate promising materials and techniques applicable to the fabrication and masking of lenticular screens.
3. Full size screens will be assembled from smaller samples fabricated using workable techniques and materials.

E. DISCRETE-PARTICLE SCREEN PERFORMANCE IMPROVEMENT

The disagreement between the measured and predicted performance of discrete-particle screens which exists is not well understood. It is important to improve this type of screen because of the inherent high resolution and potential fabrication advantages.

Theoretical limits of performance for volume scattering materials have been calculated and substantiated by measurements of bulk glass-ceramic materials. The discrete-particle screens are of this same class and were expected to demonstrate the same levels of performance;

III - 12

however, measured values of efficiency are only 60% of the theoretical values, and values of the diffuse reflectance are too great by almost a factor of two. This type of screen exhibits very high resolution; e.g., MTF = .89 at 10 lines/mm and square bar targets can be resolved with spatial frequencies in excess of 100 lines/mm.

Both theoretical and practical investigations will be conducted in an attempt to improve the performance of this type of screen.

IV. RECOMMENDED PROGRAM

The recommended schedule is shown in FIGURE 1. The schedule is based on Corning's four-week accounting periods. It will be noticed that several activities will be simultaneous for an appreciable portion of the program. This reflects the custom optical services to be utilized and specialized assistance from Departments of Corning other than the Electronic Research Laboratory. First priority has been given to initiating the system studies, together with the investigation of substrate darkening and reduction of surface reflections. Once an activity has been initiated, action in one form or another is expected until nearly the end of the program.

Two periods are allowed for sample screen fabrication and final report writing at the end of the program.

Progress will be reported in period reports.

PERIODS* FROM START OF THE PROGRAM

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

System Analysis



Substrate Darkening Investigation



Reduction of Surface Reflections



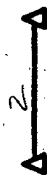
Lenticular Screens



Discrete-Particle Screen Improvement



Sample Screen Fabrication



Period Report



Final Report

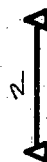


Figure 1. Recommended Schedule

TOTAL 47

*1 Period equals 4 weeks.

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VI. FACILITIES

The facilities available at the onset of the first contract have been maintained intact and additions have been made.

A 300 square foot laboratory has been set up just for display screen research and equipped with the following new instruments:

- a goniophotometer

- a modulation transfer function analyzer

- a diffuse reflectometer